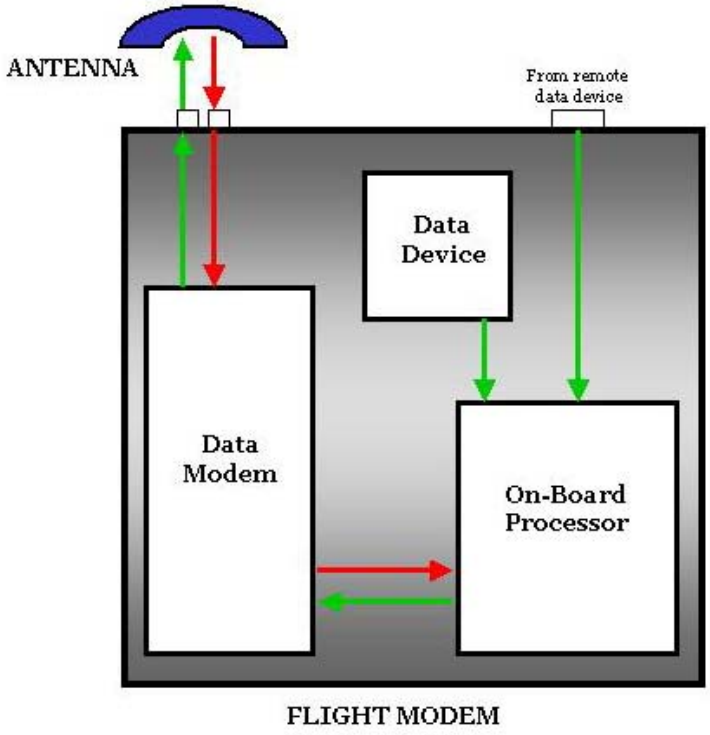
NASA Wallops Flight Facility

Testing of the Flight Modem on the NASA ER-2 Aircraft



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The NASA ER-2 aircraft

Table of Contents

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EXECUTIVE SUMMARY

The Flight Modem project has been gaining momentum as a successful platform from which to enable the transmission of low-speed data from remote vehicles to a central host computer in near real-time. Additionally, it offers a huge savings in cost compared to traditional NASA data transfer methods. Successful transmission of diagnostic network data was demonstrated in the Spring of 2001 with the flight modem aboard a sounding rocket launched out of Kiruna, Sweden. This was followed by a successful demonstration of the actual satellite data services with the modem transmitting GPS positional data from the NASA P3 aircraft out of WFF in May 2001. In July 2001, the modem performed successfully in transmitting GPS and SSR targeting data from a USAF E-9A aircraft on a test mission out of Tyndall AFB to destinations over the Gulf of Mexico.

This report documents the successful testing of the Flight Modem system aboard the NASA ER-2 aircraft out of Dryden Flight Research Center (DFRC) at Edwards AFB, California. The testing was conducted in conjunction with the Conical Scanner Microwave Infrared Radiometer (COSMIR) earth sciences mission to demonstrate operability on a high-altitude (this mission reached 67,723 feet), high-speed aircraft in an uncontrolled environment. The test included, in addition to GPS data, the transmission of temperature data from thermistors mounted within the flight modem chassis. The ability of the system to accurately remotely report this data in the semi-hostile environment was confirmed. Details of the processes, procedures and findings of the ER-2 mission and tests are detailed herein.

1.0 PURPOSE

In February 2002, the NASA ER-2 aircraft prepared to conduct a mission to for the Conical Scanner Microwave Infrared Radiometer (COSMIR) team to perform measurements over the northwest United States. The flight modem was installed in the ER-2 as a piggy-back test during one the test flights.

With the flight modem, NASA is demonstrating the capability to monitor data in a real-time mode using remote equipment (commercial off the shelf, COTS, hardware and software) and satellite IP services. The advantage of such equipment is its high utility and extreme cost savings when compared to traditional data-gathering systems and devices. The Flight Modem uses a relatively simple suite of components to collect and format data at the remote location, initiate a communications session over a commercial mobile satellite service (MSS), and transmit the data over the link to a host computer at a distant, centralized location.

In previous tests, NASA has demonstrated successful transmission of diagnostic network data with the flight modem aboard a sounding rocket and actual use of satellite data services with the modem transmitting GPS positional data from the NASA P3 aircraft out of WFF. Later, the flight modem performed successfully in transmitting GPS and SSR targeting data from a USAF E-9A aircraft from locations over the Gulf of Mexico.

This report documents flight modem testing in conjunction with the ER-2 aircraft at Dryden Flight Research Center (DFRC). In particular, it discusses the preparation of the hardware and software relative to installation on the ER-2 as well as the findings of operations during the test flight.

1.1 Scope

The scope of this report is to document the processes, procedures and data analysis gathered relative to the flight modem and its use on test flights performed on board the ER-2 aircraft at DFRC.

1.2 Structure

This report contains the following sections:

1.0 Purpose and scope of the ER-2 Flight Modem Test
2.0 Reference documents relative to the Flight Modem
3.0 Flight Modem system components including details of the hardware, software and communications.
4.0 Test results detailing operational findings of the Flight Modem flight tests, data received and an analysis and critique of the data.
5.0 Finding and conclusion.

2.0 REFERENCE DOCUMENTS

(1) *CE-SBC-SC400 Data Sheet*, Revision 2.00. RLC Enterprises Inc., 2002.

(2) *QUALCOMM Globalstar GSP-1600 Tri-Mode Phone User Guide*, QUALCOMM Incorporated, 1999.

(3) *QUALCOMM Globalstar GSP-1620 Satellite Packet Data Modem Integrator's Reference Manual*, QUALCOMM Incorporated, 2000.

(4) ARINC Characteristic 743A-4, *GNSS Sensor*, Airlines Electronic Engineering Committee, Aeronautical Radio Inc., Dec 27 2001.

(5) *NASA WFF Flight Modem Web Page*, http://www.wff.nasa.gov/~fltmodm, 2002.

3.0 FLIGHT MODEM SYSTEM COMPONENTS

The basic components of the Flight Modem system include COTS hardware & software and a satellite IP communications link. Each component is detailed in the sections that follow.

3.1 Hardware

Hardware associated with the Flight Modem used on the ER-2 flights include the physical chassis and its peripheral equipment, the on-board computer, the packet data modem, a global positioning system (GPS) receiver, three (3) thermistors and antennas for both the GPS and flight modem systems. Each of the components is discussed in the following paragraphs. **Figure 1** illustrates the basic connectivity internal to the flight modem.

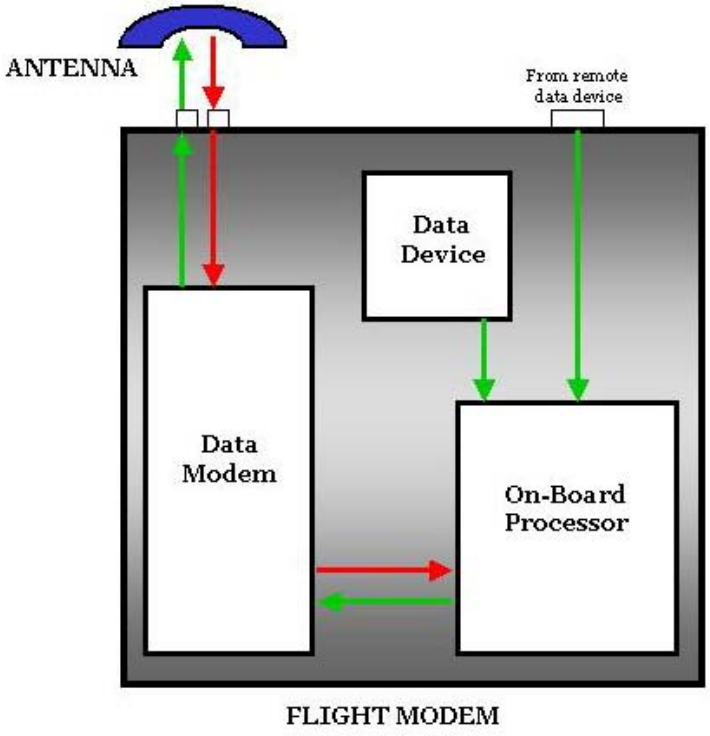

Figure 1 – Flight Modem Schematic

3.1.1 Chassis and Associated Equipment

The flight modem chassis consists of a fabricated metal box that is approximately two (2) rack units in height. It is designed to fit securely into a standard 19" equipment rack. **Figure 2** is a photograph of the actual flight modem used during this test. Note the chassis and the internal configuration of its sub-components.

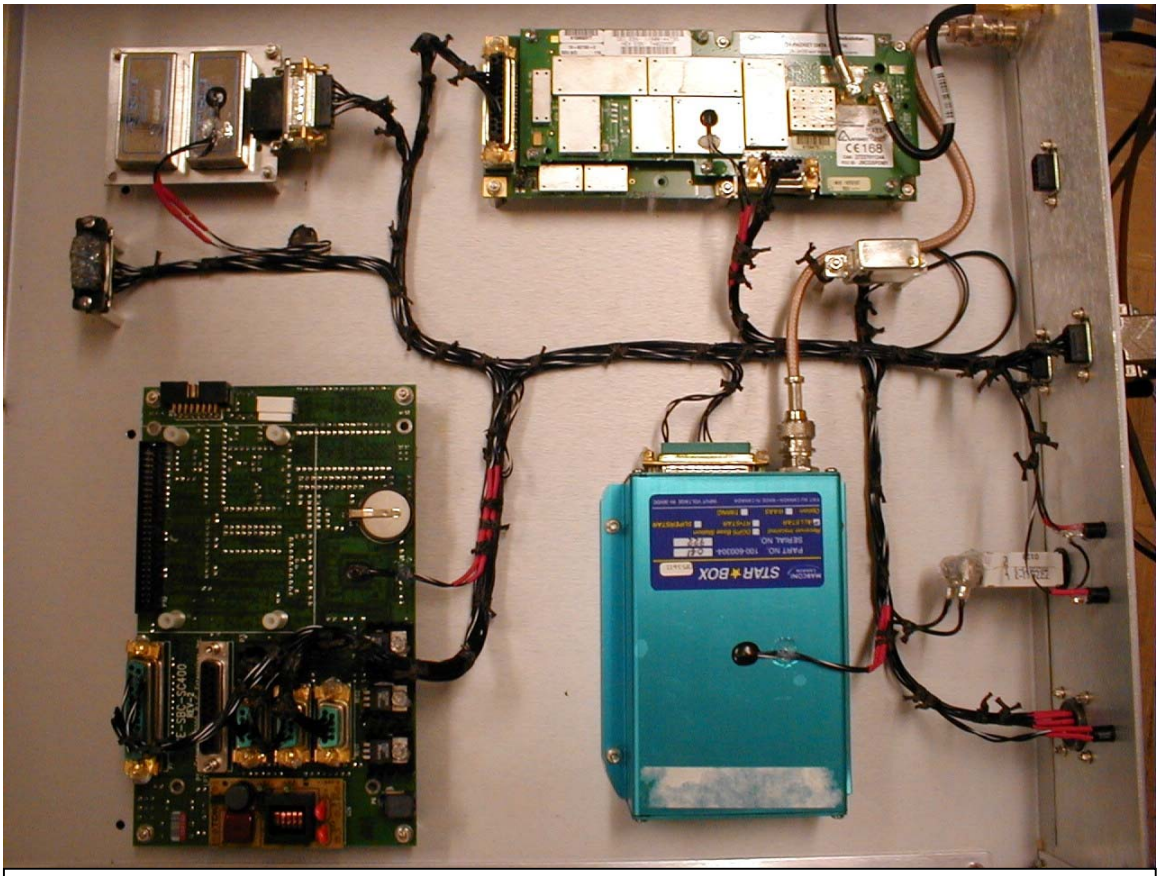

Figure 2 - Flight Modem chassis with components. Note the thermistors on the CPU board (bottom left), modem board (top right) and GPS receiver (bottom right). Although shown in this view, the thermistor on the DC/DC power supply (top left) was not used during the ER-2 flight.

3.1.2 Computer

The on-board computer for the Flight Modem system consists of a small computer, the CE-SBC-SC400, supplied by RLC Enterprises, Inc. The CE-SBC-SC400 is a single-board computer providing the central processing unit (CPU), memory, clock, graphics and PCMCIA controllers, power management, keyboard interface, I/O and storage capabilities. The unit flown on the ER-2 included an AMD ELAN SC400 486 32-bit CPU operating at 100 MHz. Memory is provided by a 16 MB DRAM with the BIOS loaded on a separate 8 MB Flash EPROM.

Storage is provided by an 8 MB "flash disk" functioning like a hard drive. Also included are three (3) serial I/O ports.

3.1.3 Modem Assembly

The modem assembly provides connectivity to the communications service necessary to transmit the on-board data to the remotely-located host. Globalstar is the service provider and furnishes the modem and antenna system for use with its packet data and voice services. All these components are manufactured by Qualcomm. For this application, the GSP-1620 packet data modem was used. An aircraft antenna (manufactured by ANTCOM Corp.) was used and mounted on the outside top of the ER-2 fuselage over the main Q-Bay. The antenna was connected to the chassis mounted inside the Q-Bay using two (2) 10-foot coaxial cables with SMA connectors to attach to the Tx/Rx plugs at the chassis to the same on the antenna.

3.1.4 GPS and Thermistor Data System

The GPS system includes a Star Box/Motorola GPS receiver and an antenna mounted out on the wing of the ER-2. The system operates at L1 frequency with C/A code. The antenna cable connection to the receiver was a standard coaxial cable outfitted with BNC connectors that was extended from the flight modem chassis to a patch panel in the ER-2's Q-Bay. From the patch panel, the internal wiring of the ER-2 snaked through the fuselage and wing to eventually reach a button-type antenna on the top surface of the ER-2's left wing.

The GPS receiver was programmed to provide GPS data in a standard NMEA format at one sample per second of both GGA and GSV information (basic satellite and positional GPS data). The data was available via a serial port on the receiver that connected to the on-board computer by cable.

Three (3) thermistors were also installed within the flight modem chassis, one each on the GPS receiver, computer CPU board and data modem board. Temperature data collected by these devices was relayed to the on-board computer for transmission to the host on the ground.

3.2 Software

System software was comprised of two primary components: the operating system of the on-board computer and the application software. Each of these is explained in the following sections in more detail.

3.2.1 Operating System

The operating system used for the on-board computer was Microsoft Windows CE, version 3.0. On the receiving computer (laptop), Microsoft Windows 98 SE was installed.

3.2.2 Application Software

The applications software is comprised of two (2) components: the flight computer software that is installed on the on-board computer and the "control" software that runs on the remote host computer. The *flight computer software* was developed in the C++ computer language and performs the following functions:

1. Establishes a communications link to the Internet by "hand-shaking" and commanding the packet data modem to dial the Globalstar gateway.
2. Establishes a communications "pipe" to the host computer by opening a "socket" or port at the pre-determined IP address for connection by the host computer.
3. Handles hand-shaking with and parsing of data arriving from the GPS receiver.
4. Sets up log files to collect and store GPS, thermistor and system diagnostic data.
5. Transmits GPS and thermistor data to the host computer when the communication link is up and the socket connected.
6. Awaits commands from the host computer to perform the following functions:
    a. AUTO MODE: sets a flag to transmit data to the host computer only at predefined intervals and not on a continuous basis. For the ER-2 test, AUTO MODE, when used, was set to transmit for fifteen (15) minutes and "sleep" for ten (10) minutes in a continuous loop. AUTO MODE was developed to limit the "on-air" time of the phone to save costs where appropriate.
    b. HANG-UP: sends a command to the modem to hang-up the connection and not attempt a re-dial. The Flight Modem will NOT communicate again with the host computer unless the on-board computer is reset either by pressing the RESET button or by cycling the power on the chassis. HANG-UP mode was developed so that the modem could be deactivated in case of interference with other systems.
    c. CLEAR FILE: this command effects the erasure of the GPS and or other data files file on the on-board computer's hard drive. This command was developed to permit the deletion of preliminary test data. Since new data is appended to the old data files when a new session is initiated, we wanted to have the ability to "refresh" the data files on-command. This feature allows for an easy way to initialize (e.g., zero-out) the file at the beginning of a mission.

The *host control software* was developed in the C++ computer language and performs the following functions:

1. Provides the ability to initiate a connection by opening a socket to receive data coming from the flight computer at a static IP address.
2. Logs the received data on the local hard drive in a text file.
3. Provides some elementary error detection by examining checksum information in the data frames.
4. Provides a visual output of the incoming raw streaming data.
5. Provides a real-time, dynamic depiction of latitude, longitude and altitude as well as GPS time and thermistor data.
6. Provides the ability to initiate the AUTO MODE, HANG-UP and CLEAR FILE commands.

Figure 3 - Installing the flight modem into the ER-2 Q-Bay.

3.3 Communications

The communications channel used during the ER-2 flight testing was provided by Globalstar's satellite packet data service. This service provides a synchronous data link operating at 9600 bits-per-second. Globalstar transmits in the frequency band 1610-1625 MHz via commercial low-earth orbiting satellites

(LEOS) orbiting at 1440 km above the surface of the earth. The signal is sent from the satellite transponder to a terrestrial earth station that provides a gateway into

Figure 4 - Flight modem installed in the 19" rack in the Q-Bay of the ER-2.

the Internet. Transmitter output power is regulated to between 0.4 and 2.0 W.

TCP/IP communications protocols were used for this test. The host computer was assigned an IP address that was part of the network domain included with the Telemetry Lab at WFF from where the testing was conducted.

4.0 TEST RESULTS

The Flight Modem was installed in the ER-2 in a horizontally-situated 19" rack in the aircraft's Q-Bay just behind and below the cockpit area. A single cable was installed for the GPS receiver from the chassis to the Q-Bay patch panel that, in turn connected to the GPS antenna on the wing. Total distance between the chassis and the GPS antenna was approximately 25 feet with a many as twelve (12) separate coaxial connectors in the run. Two (2) cables (one transmit and one receive) were installed between the FM chassis and the ANTCOM antenna

located almost directly above at the top of the ER-2 fuselage and, notably, only about 18" forward of the aircraft's primary GPS antenna (this is discussed in more detail relative to EMI/RFI in Section 4.2). Total distance from the chassis to this antenna was about 4 feet, though 10-foot cable runs were used. **Figure 3** shows the modem being installed into the ER-2's Q-Bay. **Figures 4** and **5** show different shots of the flight modem mounted into the 19" rack within the Q-Bay.

Figure 5 - Another shot of the flight modem in the Q-Bay from a different angle.

Testing was conducted first on the ground and then during one of the ER-2 test flights relative to the COSMIR mission. Results from the test flight are summarized in the following sections, respectively.

4.1 ER-2 Project Flight Test

The Flight Modem was tested in-flight for basic operations including the command elements of the system (AUTO MODE, HANG-UP, CLEAR GPS FILE) on February 25, 2002. Prior to take-off, the power was applied to the flight modem and data was monitored for about 10 minutes before take-off and then

for a full hour into the test flight to demonstrate that the system was working properly. The total duration of the test was approximately one hour and ten minutes with "system-on" at approximately 16:30:00 GMT and take-off occurring at approximately 16:40:00 GMT. Testing continued until approximately 17:40:00 GMT when it was determined that all aspects of the system seemed to be working properly.

Data was collected on the ground by the receiving laptop and in the air by the on-board computer for the ten minutes prior to take-off and the first 30 minutes of the flight when the 15-10 AUTO MODE feature was invoked at approximately 17:15:12 GMT. At that time, the communications link was closed so that only the on-board computer continued to log data. After 15 minutes, the AUTO MODE feature in the FM instructed the modem to re-establish connectivity which was accomplished successfully, allowing the ground computer to again begin logging data – this occurred at approximately 17:30:33 GMT. Both computers were then again logging data until the test ceased ten minutes later at approximately 17:40:00 GMT.

Overall, the Flight Modem system worked exactly as planned during the entire duration of the test. No errors were noted in the collection of the GPS or thermistor data and satellite lock was not lost during the entire flight (except of course during the commanded "turn-off" when AUTO MODE was invoked). Data was collected for positioning and temperature information on both the on-board FM and ground host computers. This provided profiles of the ER-2 flight with respect to altitude, latitude and longitude respectively as depicted in the three (3) charts presented in Appendix A. Note, the only difference between the flight and ground data sets is that, as expected, the ground data lacks the 15-minute period when the AUTO MODE turned off the flight modem.

Additionally, temperature data was logged and analyzed. Appendix B presents this data showing the temperature profile of the GPS receiver, modem and computer boards relative to altitude of the ER-2 as logged by the GPS receiver. The two (2) charts presented in Appendix B represent the data logged on the on-board computer and the data collected by the ground computer, respectively. Again, the only difference between the flight and ground data sets is that the ground data lacks the 15-minute period when the AUTO MODE turned off the flight modem. *Note, though an interesting effect on the flight data charts – when the modem was turned off, the temperature of the modem board dropped at a faster rate than before the action. Fifteen minutes later, when the modem was re-activated, the temperature made an abrupt rise, signaling the warming of the electronics when turned back on.*

4.2 EMI/RFI

A question arose prior to the test flight whether the transmit from the GlobalStar antenna would interfere with the aircraft's GPS receive antenna. Though the GlobalStar transmit frequency is limited to the 1610-1625 MHz band and the GPS

receive frequency is centered at 1575.42 MHz, it was wondered whether their close proximity might cause problems. The "recommended" specifications provided by GlobalStar/Qualcomm suggest a minimum separation of 30"

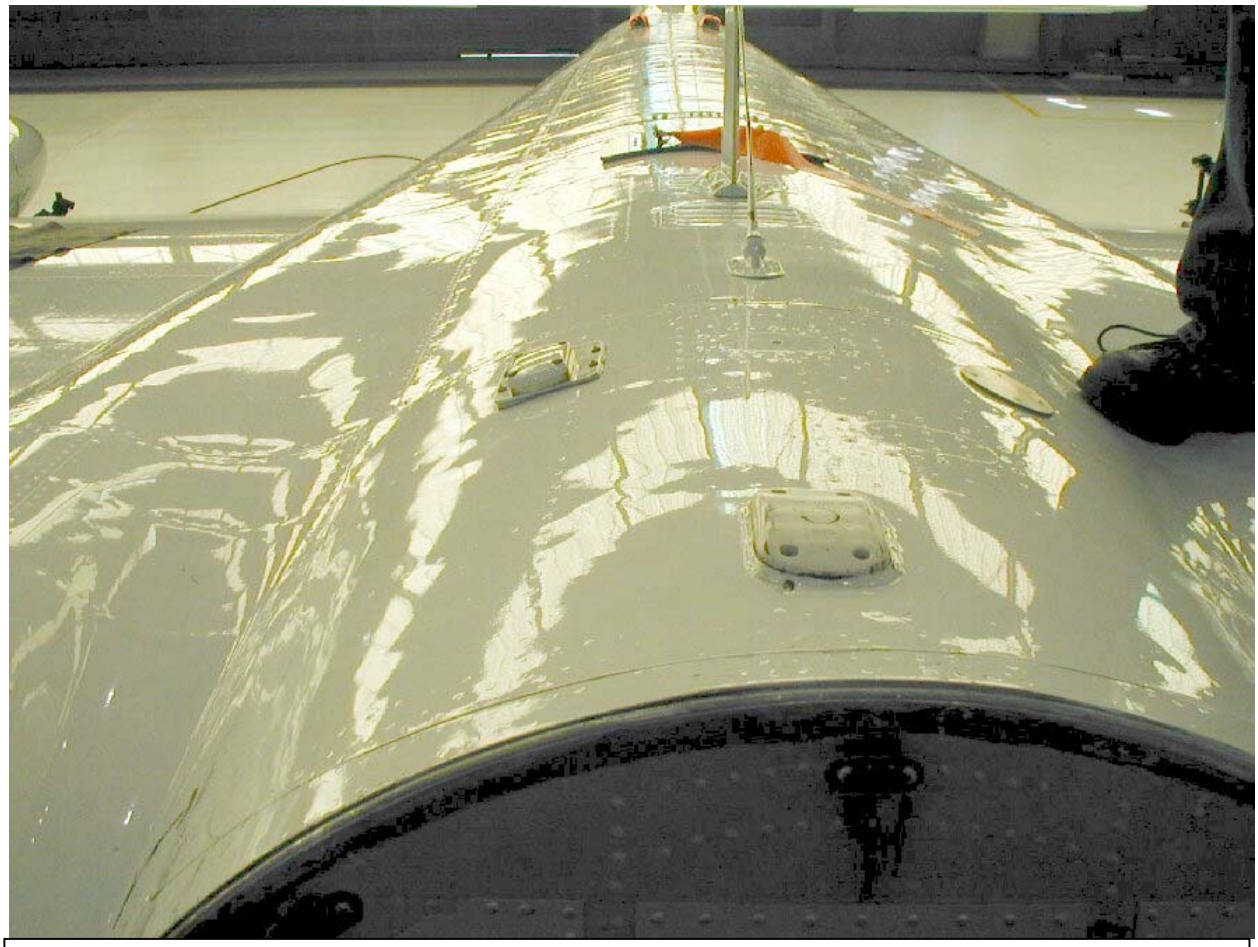

Figure 6 - Relative position of the ER-2's primary GPS antenna (front, center) and the flight modem's GlobalStar transmit/receive antenna (left and aft of the GPS antenna). Total separation between the two is approximately 18".

between such antennas and our installation provided a separation of only 18". **Figure 6** shows the relative position of the two antennas.

The ER-2 GPS receiver is a Litton LTN-2001 model that is designed around the ARINC 743 specification. In discussions with the product engineers at Litton (that division is now owned by Northrup Grumman), they deferred to the characteristics described in ARINC-743 when asked if they thought there would be any interference issues between the GlobalStar and LTN-2001 systems. ARINC-743 shows a sharp rejection mask at 1610 MHz and higher. Additionally, previous testing of the flight modem with a frequency spectrum analyzer has shown that spurious signals that may emanate from the GlobalStar carrier(s) are at least -90 dBm or lower in the 1575 MHz GPS band. All this, coupled with the fact that GlobalStar has voluntarily limited transmission to 1616 MHz and higher

within their assigned band, helped the team come to the hypothesis that there should be little or no interference between the systems.

All this information was laid out to the Mission Manager at DFRC in a telephone consultation prior to the COSMIR test flight. Additionally, it was also pointed out that the GPS system was not flight-critical or pilot-safety impacting and, if an issue did arise, the pilot still had the ability to turn off the FM via a remote switch located in the cockpit. The Mission Manager pronounced the test a "go" and the flight modem was prepared for testing.

During the ground test and flight, there were no reported electromagnetic or other radio frequency interference (EMI/RFI) problems caused by the flight modem transmitter to the GPS system or any other instrumentation system on the ER-2. Similarly, the aircraft instrumentation did not interfere with the operations of the Flight Modem.

5.0 FINDINGS AND CONCLUSION

This report has presented information relative to the NASA Flight Modem system and its testing aboard the NASA ER-2 aircraft. Various components of the system were discussed with details presented on hardware, software and communications. The flight modem tests included GPS and thermistor data flows using over the horizon IP satellite communications, on-board computer logging, and near real-time terrestrial terminal logging via the Globalstar satellite constellation. All Flight Modem system functions performed as expected and did not cause any interruption in data streaming or RF interference with other on board instruments.

APPENDIX A

GPS Data Collected on the ER-2 Test Flight

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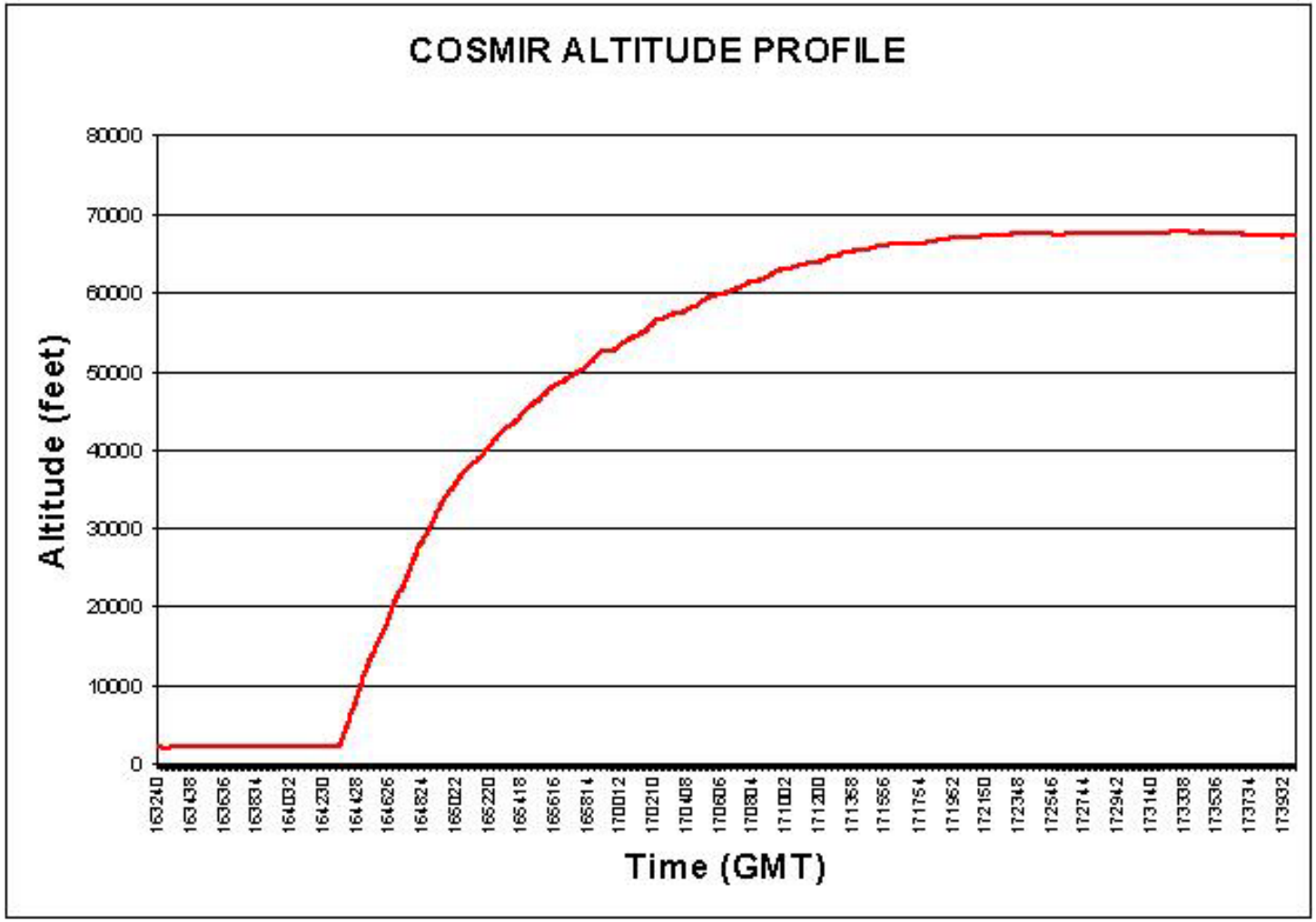
GPS Data Collected on the ER-2 Test Flight

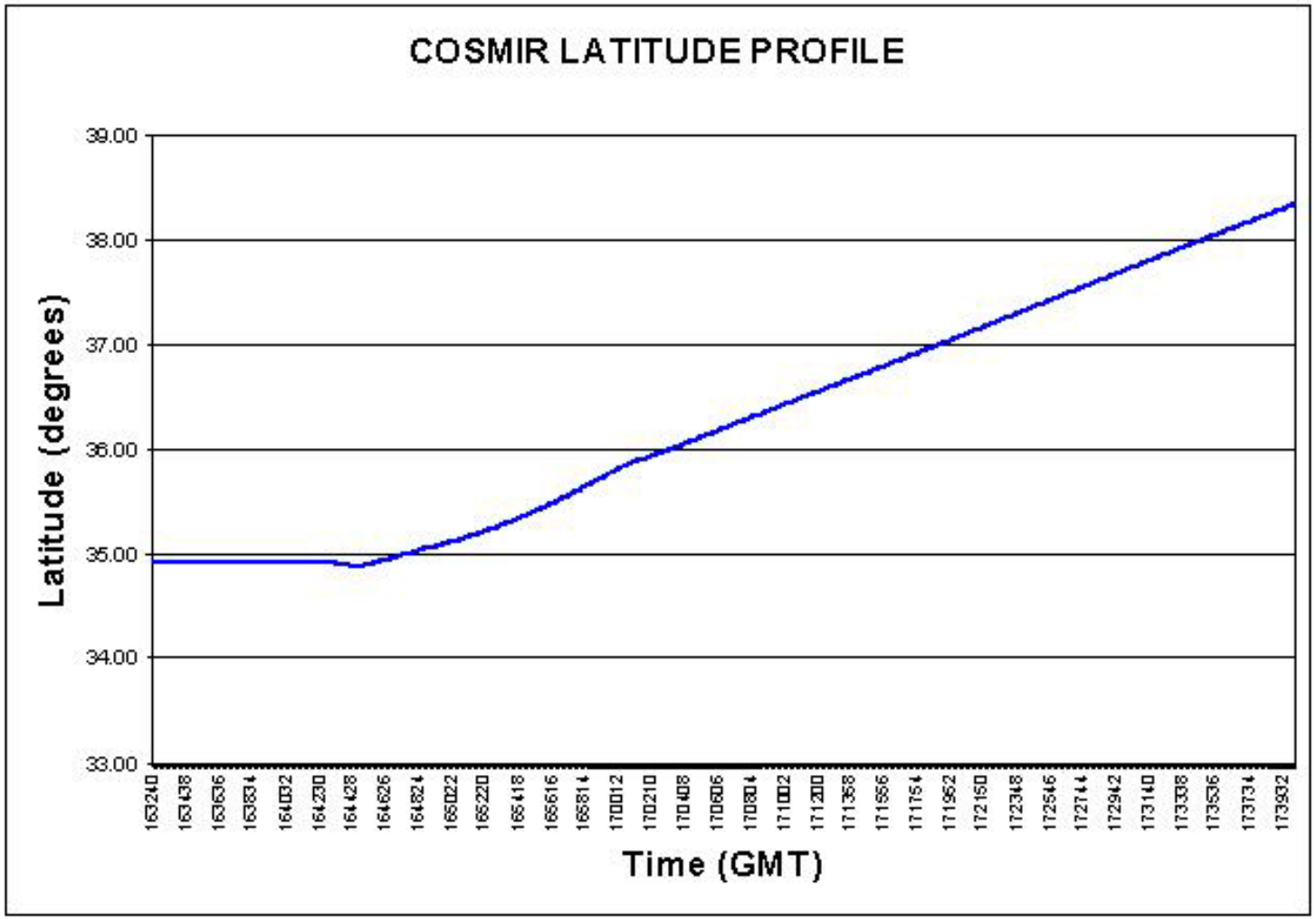
The following charts present the altitude, latitude and longitude profiles for the ER-2 as logged by the on-board flight modem computer (the first three charts, respectively) and by the host on the ground (the last three charts, respectively). Note that both sets of data are identical, as expected, except for the 15-miunte AUTO MODE outage when the ground computer was not connected to the flight modem.

(see next page)

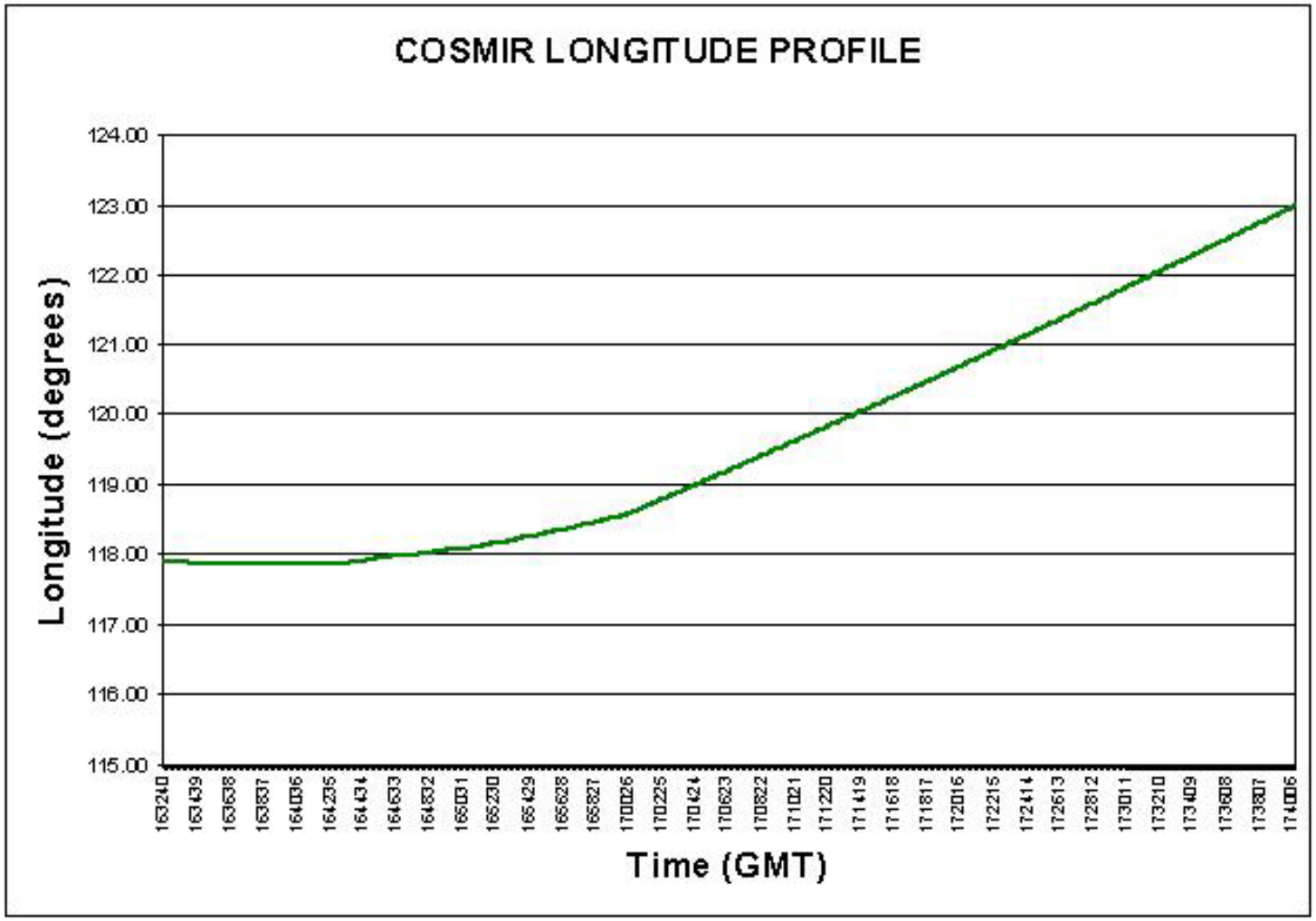
ON-BOARD FLIGHT MODEM COMPUTER ALTITUDE CHART



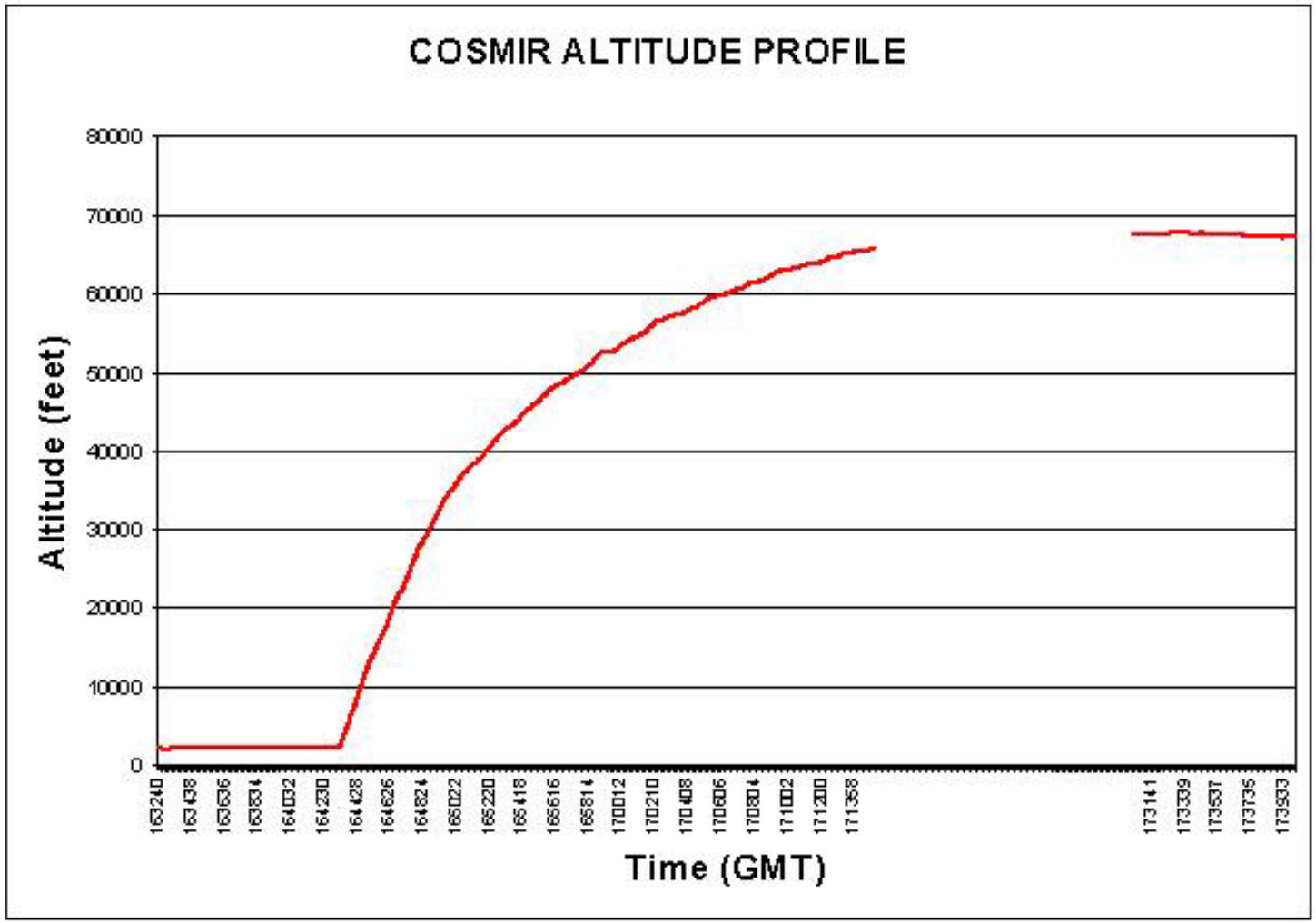
ON-BOARD FLIGHT MODEM COMPUTER LATITUDE CHART



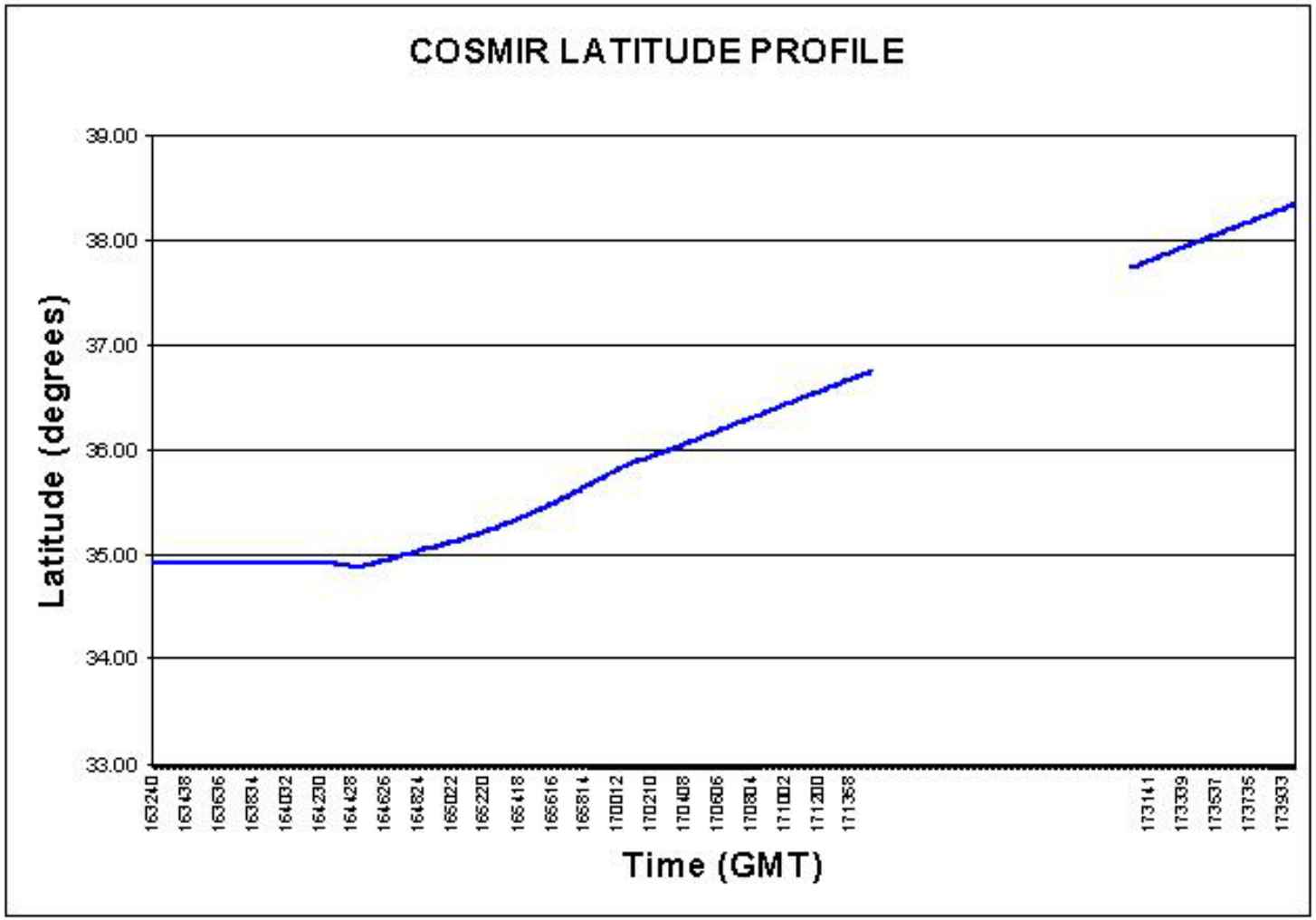
ON-BOARD FLIGHT MODEM COMPUTER LONGITUDE CHART



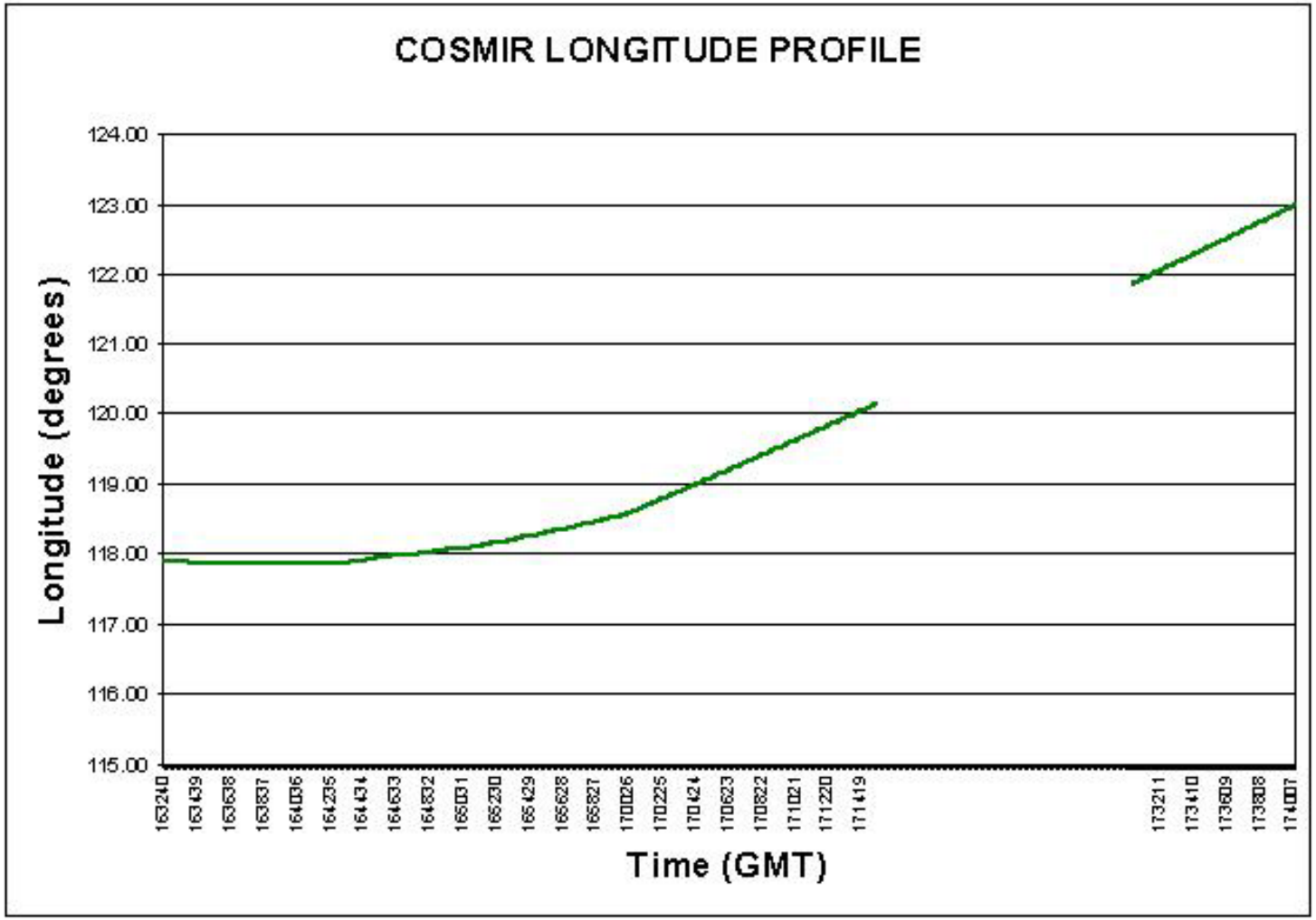
GROUND COMPUTER ALTITUDE CHART



GROUND COMPUTER LATITUDE CHART



GROUND COMPUTER LONGITUDE CHART



APPENDIX B

Thermistor Data Collected on the ER-2 Test Flight

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Thermistor Data Collected on the ER-2 Test Flight

The following charts present the temperature data from the three (3) thermistors installed within the flight modem chassis. The plots show the temperature, respectively, of the CPU, modem and GPS receiver relative to altitude of the ER-2 during testing. The first chart represents data from on-board flight modem computer and the second chart , data from the host laptop on the ground. Note, again, that both sets of data are identical, as expected, except for the 15-miunte AUTO MODE outage when the ground computer was not connected to the flight modem.

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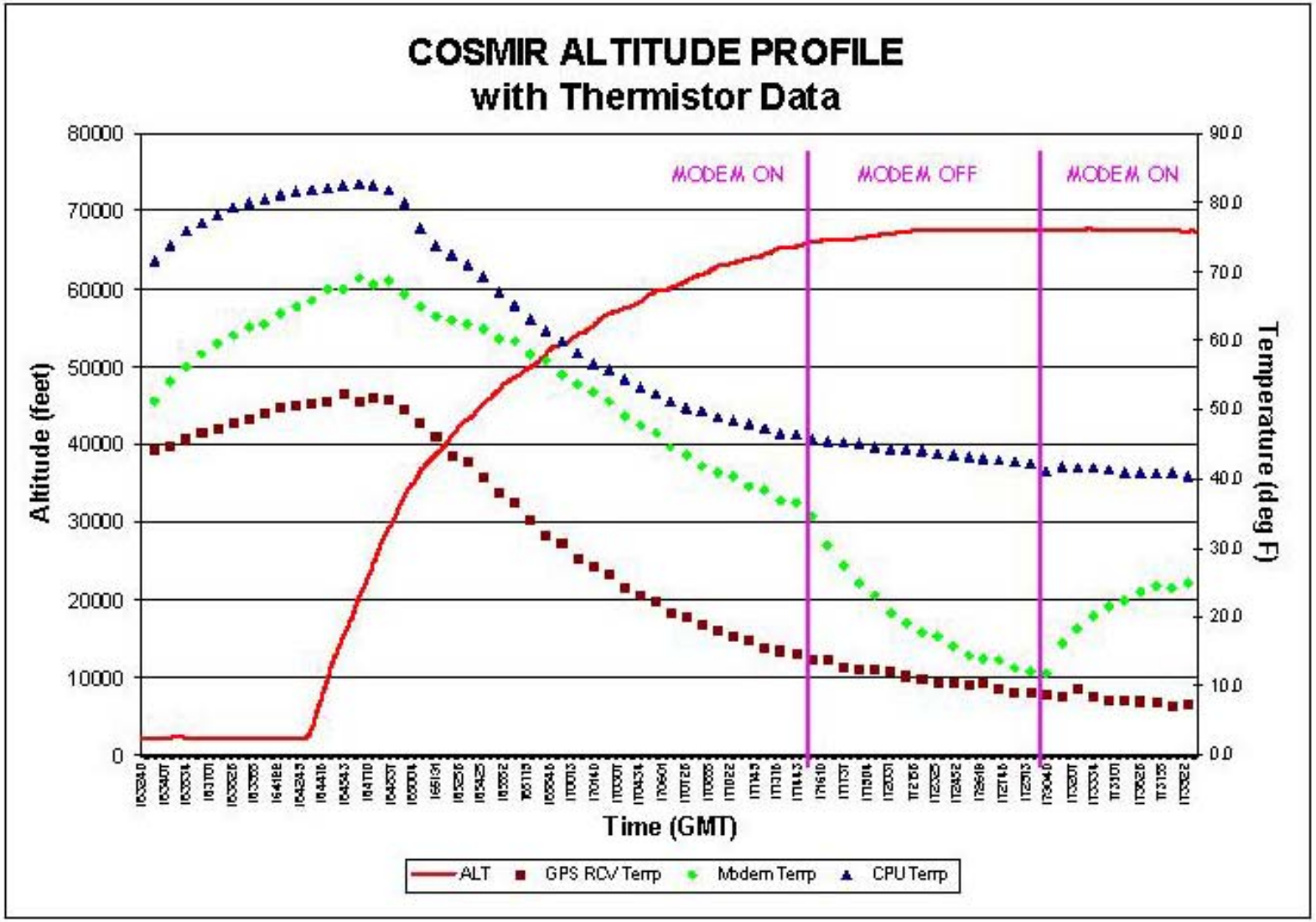
ON-BOARD FLIGHT MODEM COMPUTER TEMPERATURE CHART



GROUND COMPUTER TEMPERATURE CHART